

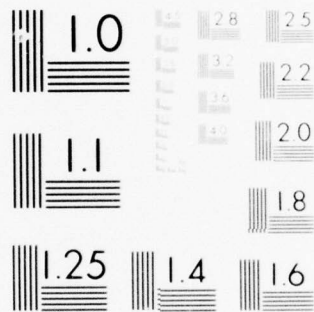
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## SUMMARY

This report contains information, data, and concepts essential to the understanding of artificial lighting and its impact on energy conservation. The key to lighting energy conservation is system control. The report discusses the types of controls that can be utilized in a lighting system. The impact on energy saving by properly integrating the two sources of light (artificial lighting and natural daylighting) were examined.

## PREFACE

This report was prepared under Work Unit 4A762731AT41-T6-017, Energy Conservation Methods.

COL James R. C. Miller is Commander and Director of FESA and Mr. Homer D. Musselman is Chief, Research and Technology Division. Mr. Lewis Keller (DAEN-FEU-M) is Technical Monitor.

## INTRODUCTION

Lighting is a major consumer of electrical energy in office buildings, both for the energy required to operate the luminaires and for removing the heat being generated from these luminaires in air conditioned spaces.

Energy consumption for lighting (kilowatt-hours) is the product of power input to the luminaries (kilowatts) and the time duration for which the luminaries are being used (hours). Thus, to achieve maximum energy saving from lighting, both power input and time of use should be controlled.

Power input can be reduced by the proper design of the lighting system which includes the selection of visual tasks, light sources, room finishes, wiring and switching. The time of use for lighting is directly related to the working hours and management policy.

## I. Artificial Lighting Design

From the past few years, more efficient light sources have increased in number rapidly, interior lighting levels have continued to rise dramatically. These higher lighting levels have caused more complaints than the previous lower lighting levels. This was because the newer lighting layouts designed ignored the many parameters that need to be considered. These parameters are the key to designing lighting systems that provide improved visibility and better energy conservation.



## 1-1 Photometric Terminology and units

= Luminous Energy ( $Q_v$ ): Energy traveling in the form of electromagnetic waves to which the human visual system is sensitive. Units: Lumen-seconds

= Luminous flux ( $\phi$ ) = The time rate of flow of luminous energy ( $Q_v$ ) emitted, transferred, or received by a surface.

$$\phi = \frac{dQ_v}{dt} \quad \text{units: lumen}$$

= Lumen: The unit of luminous flux. It is the flux emitted within a unit solid angle (1 steradian) by a point source having a uniform luminous intensity of 1 candela.

$$\text{Lumen} = \frac{1 \text{ candela}}{\text{steradian}}$$

= Steradian ( $w$ ): A geometric relation which is the ratio of the sphere area enclosed by a solid angle to the radius of the sphere squared.

$$w = \frac{A_{\text{sphere}}}{r^2} \quad \text{Units: radians}$$

= Luminous Existence ( $M$ ) = The luminous flux emitted by a very small surface divided by the area of that surface element.

$$M = \frac{d\phi}{dA} \quad \text{units} \quad \text{Lumens/meter}^2$$

Also known as the density of luminous flux emitted.



= Illuminance (E) = The luminous flux incident on a small surface per unit area of that area

$$E = \frac{d\phi}{dA}$$

$$\text{Units} = \text{lumens/meter}^2 \text{ (lux)}$$

$$\text{lumens/meter}^2 \text{ (foot candle)}$$

Also known as the density of luminous flux incident on a surface and commonly referred to as illumination.

= Luminous Intensity (I) = The luminous flux per unit solid angle in a given direction

$$I = \frac{d\phi}{d\omega}$$

$$\text{Units} = \text{lumens/steradian} = \text{candela (cd)}$$

Luminous intensity is commonly referred to as candlepower.

= Luminance (L) = The luminous flux leaving a point in a given direction ( $\theta$ ) per unit of projected area of that point per unit solid angle in which the flux is contained.

$$L = \frac{d^2\phi}{d\omega dA \cos\theta}$$

Since luminous intensity is defined as  $I = \frac{d\phi}{d\omega}$ , luminance is also defined as

$$\text{Units } L = \frac{dI}{dA \cos\theta} \quad \text{Candela/meter}^2$$

In the United States luminance is usually given in foot lamberts (fL) where  
 $1 \text{ fL} = 3.426 \text{ cd/m}^2$

= Lambertian Surface (Perfect Diffuser): A surface that absorbs all incident radiant energy and reradiates all that energy according to Lambert's Cosine Law.

= Lambert's Cosine Law = States that the intensity at any angle is equal to an intensity normal to the surface times the cosine of the angle (Fig 1-1) (from CEL handbook)

$$I_{\theta} = I_n \cos \theta$$

= Reflectance ( $\rho$ ) = The ability of a surface to reradiate energy.

$$\rho(\%) = \frac{\text{total reflected energy}}{\text{total incident energy}} \times 100\%$$

= Transmittance ( $\tau$ ) = The ability of a surface to pass radiant energy.

$$\tau\% = \frac{\text{total transmitted energy}}{\text{total incident energy}} \times 100\%$$

= Efficacy ( $\xi$ ) = The ratio of light output to electrical input

$$\xi = \frac{\text{total luminous flux emitted}}{\text{total input power}}$$

Units: lumens/watt

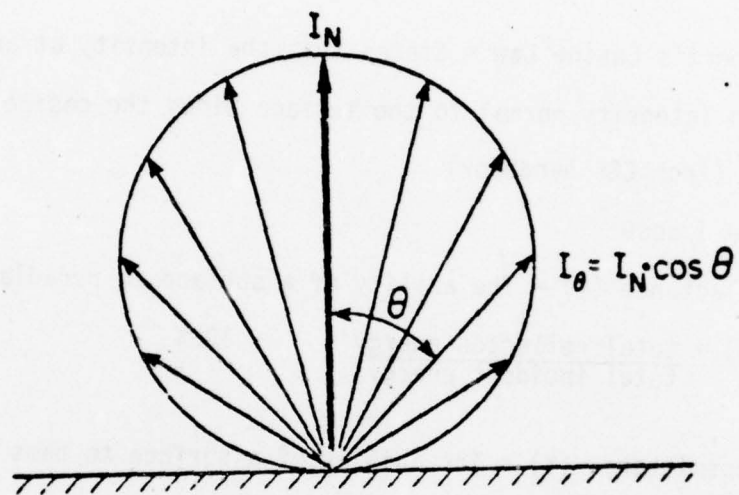


Figure 1-1 Lambert's Cosine Law (Perfect Diffuser)

## 1-2 Light Sources

Light sources (lamps) can be divided into two main categories:

- A. incandescent
- B. gaseous discharge

The gaseous discharge type of lamp is either low pressure or high pressure. Low pressure gaseous discharge sources are the fluorescent and low pressure sodium lamps. Mercury vapor, metal halide, and high pressure sodium lamps are considered high pressure gaseous discharge sources.

### 1-2-1 Incandescent Sources

**Incandescent Lamps:** The incandescent lamp produces light by passing current through a wire (filament), and it is the most commonly used source even though it is the least efficient.

One of the most important characteristics of any light source is its ability to convert electrical energy into luminous energy. This is known as lamp efficacy. The incandescent lamp has efficacies ranging from 4 lumens/watt to 24 lumens/watt. For comparison purposes the incandescent lamp is typically said to have an efficacy of 20 lumens/watt.

Cost of light not only depends on the efficacy of the source but also on its life. Incandescent lamps have an average life of 1,000 hours or about 5 months for a typical burning period of 8 hours/day (52 wk/yr x 6 days/wk x 8 hr/day = 2,496 hours/yr). Lamp life is a function of many factors including filament configuration and support, fill gas, on-off cycles, and wattage.

The relationship between life and rated wattage is inversely proportional, i.e., the lower the wattage of the lamp the longer the life. Fig 1-2 (from CEL handbook)

The energy saving lamps on the market now make use of different fill gases. These lamps are krypton rather than argon gas used in conventional lamps. The result is a decrease in wattage without a decrease in efficacy. As an added benefit the life is increased. With these improvements, why haven't manufacturers been producing the lamps before? The incandescent lamp is still so popular because of its low cost. The energy saver lamps on the other hand are about 10 times the cost of an equivalent conventional lamp. Fig 1-3 (from CEL handbook)

#### 1-2-2 Gaseous Discharge Lamps

The second category, gaseous discharge, includes those sources that produce light by passing a current through a vapor at high or low pressure.

##### Fluorescent Lamps

The fluorescent lamp is a tube containing mercury and an inert gas, and lined with phosphors.

The efficacy of the fluorescent lamp is quite high, up to 80 lumens/watt.

Besides the cost of the lamp and its efficacy, lamp economics must also consider lamp life. The rated life of fluorescent lamps averages 22,000 hours.



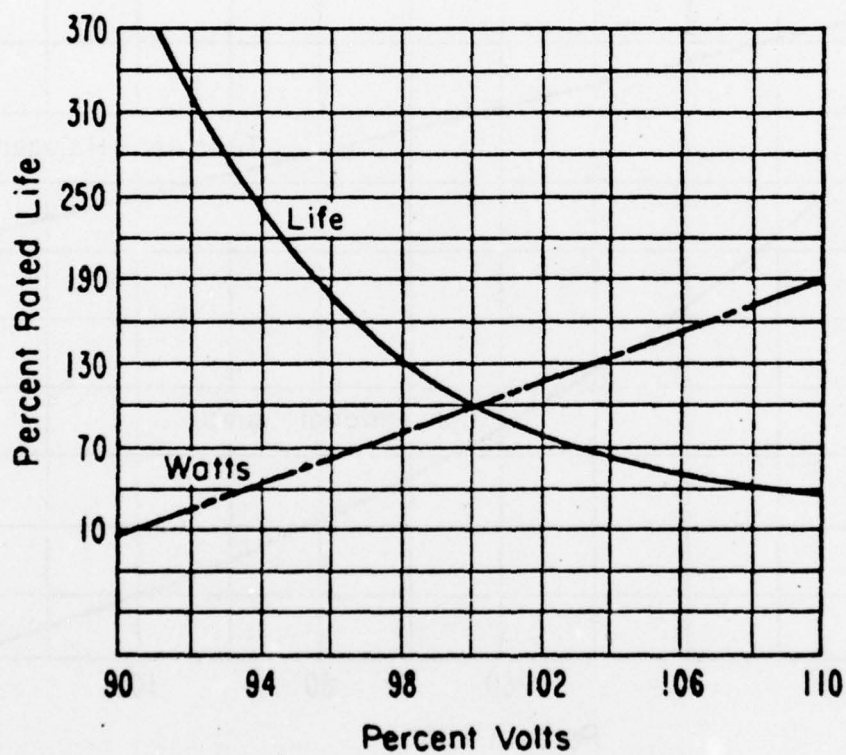


Figure 1-2 Over and Under Voltage Effect on Lamp Life



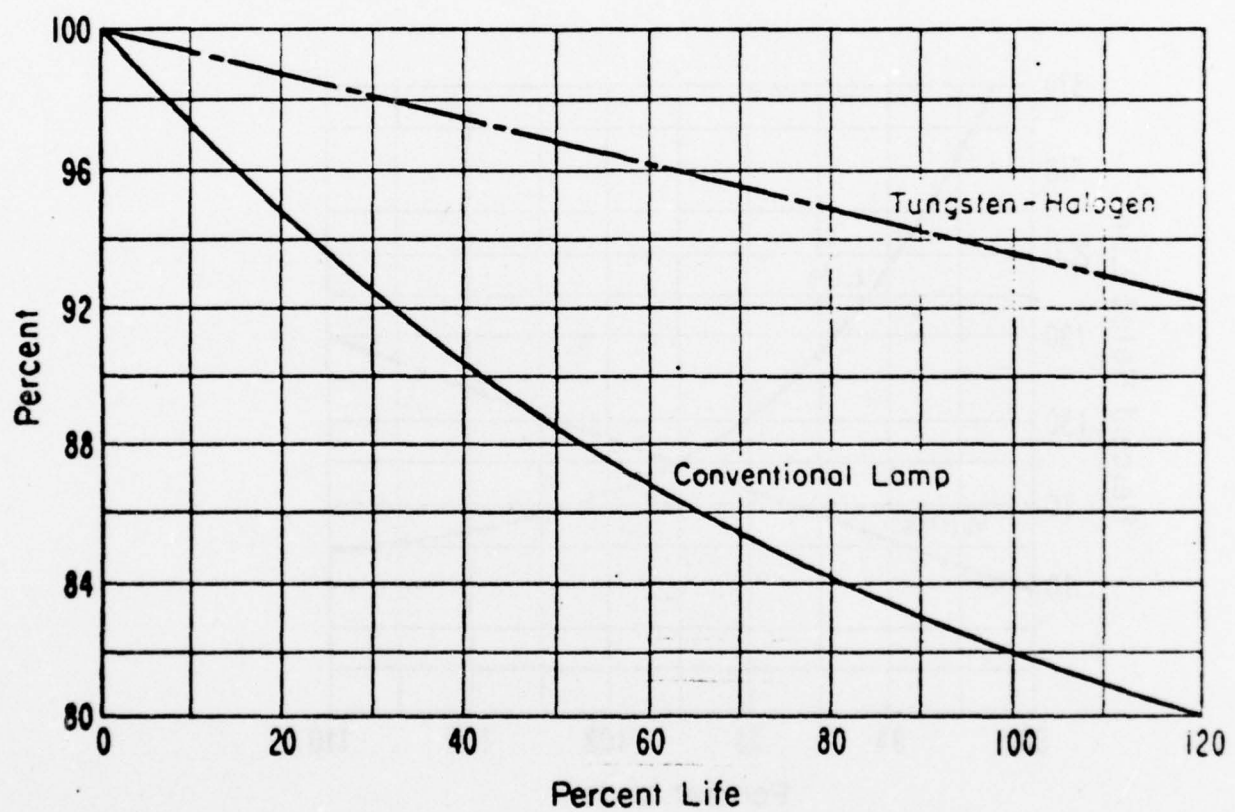


Figure 1-3 Lumen Depreciation of T-H and Conventional Lamp

### Low Pressure Sodium Lamps

The low pressure sodium lamp has the highest efficacy of all sources. Producing about 180 lumens/watt, the low pressure sodium lamp is widely used throughout Europe for roadway lighting. The life of the low pressure sodium lamp is about 18,000 hours. At the pressure at which the low pressure sodium lamp operates, sodium emits radiation at 589 and 589.6 nm (nanometer). This is yellow in color and thus the color rendering of the lamp is nonexistent. All colors appear a different shade of gray or brown.

### Mercury Vapor Lamps

The mercury lamp produces light by electron collisions in mercury gas at high pressure. Lamp efficacy ranges from about 30 to 60 lumens/watt. The mercury vapor is one of the longest lived sources, with a rated life of 24,000 burning hours.

### Metal Halide Lamps

An improvement on the mercury vapor lamp was made with the addition of halide salt to the arc tube. Metal halide efficacies average 100 lumens/watt. Life of a metal halide lamp is somewhat less than an equivalent mercury vapor, averaging about 16,000 hours for the various wattages.

### High Pressure Sodium Lamps

The high pressure sodium lamp's radiation is spread out across the spectrum rather than being limited to two bands as in the low pressure sodium lamp. For the high pressure sodium lamp, efficacy averages 125 lumens/watt with a rated life of 20,000 hours.

### 1-2-3 Summary

The light sources just discussed represent the major sources for artificial lighting. The factors that are important in choosing which of these to use are efficacy, life, color rendering ability, and source size. Dimming ability is also a consideration. To better evaluate the sources, Table 1-1 compares them on an equal wattage basis and Table 1-2 compares them on equal lumen output.

### 1-2-4 A brief summary of light sources as they apply to exterior lighting:

Incandescent lamps should be avoided for exterior applications because of their low efficiency and short life. Incandescent lamps create high operating and maintenance costs.

Fluorescent lamps should be avoided for exterior applications because of their sensitivity to temperature and the poor quality of optical control.

Low pressure sodium lamps produce monochromatic yellow light which turns all colors except yellow, gray, brown, or black. The lamp alone has a very high efficiency. However, when the source is combined with a ballast and luminaire the overall efficiency of the system is low. Because of its overall lower system efficiency and poor color rendition, low pressure sodium applications should be analyzed very carefully.

Mercury vapor lamps require a phosphor coating if color rendition is to be acceptable. The phosphor coated lamp represents a large source which

Table J-1

Source Comparison Based on Equal Watts (400 watts)

Lamp	Design	Quantity	Watts (Total)	Lumens (each)	Source Efficacy (each)	BTUH (Total)	Life HRS (each)	Cost (Total)
Incandescent	100A19	4	400	1740	17.4	1364	750	(.50) 2.00
Tungsten-Halogen	Q400T4/CL	1	400	7500	18.8	1364	2000	16.25 (1.67) 16.70
Fluorescent	F40CW	10	400	3150	78.9	1364	20000	16.70 (40.00)
L.P. Sodium	SOXL35	3	405	21500	159.3	1381	18000	120.00
Mercury Vapor	H33GL-400/DX	1	400	22500	56.3	1364	24000 <sup>+</sup>	15.50
Metal Halide	M400/BU-HOR	1	400	34000	85.0	1364	15000	34.50
H.P. Sodium	LV400/BU	1	400	50000	125.0	1364	20000	60.00

<sup>+</sup> Rated Life = 24000 hrs, Usable Life = 16 - 18000 hrs.



Table 1-2  
Source Comparison Based on Equal Lumens (30,000 Lms)

Lamp	Design	Quantity	Lumens (Total)	Watts (each)	Source Efficacy (each)	BTU/H (Total)	Life HRS (each)	Cost (Total)
Incandescent	100A19	17	(1740) 29580	100	17.4	5797	750	(.50) 8.50
Tungsten-Halogen	Q400TH/CL	4	(7500) 30000	400	18.8	5456	2000	(16.25) 65.00
Fluorescent	F40CW	10	(3150) 31500	40	78.9	1364	20000	(1.67) 16.70
L.P. Sodium	SOX180	1	33000 (13000)	180	183.3	614	18000	60.00
Mercury Vapor	H37KC-250/OX	2	26000	250	52.0	1705	24000 <sup>+</sup>	(18.75) 37.50
Metal Halide	M400/BU-HOR	1	34000	400	85.0	1344	15000	34.50
H.P. Sodium	IU250/BU/S	1	30000	250	120.0	853	15000	64.00

<sup>+</sup> Rated Life = 24000 hrs, Usable Life = 16 - 18000 hrs.

means that optical control is poor and utilization decreases. The mercury vapor lamp also has a relatively low efficacy which makes it the third choice for exterior applications.

Metal halide and high pressure sodium lamps have relatively small light emitting elements (arc tubes) which allow for good optical control. Each of the two sources has high lamp efficacy and good system efficiency. This makes these two sources the first and the second choices for exterior applications. The metal halide has better overall color balance and is preferred where color is important. The high pressure sodium has a dominant orange appearance that may be objectionable for some applications.

### 1-3 Light Control

The light sources discussed in the previous section provide us with a source of luminous flux. To control or redirect the light where we want it, materials are used having one or more of the following three basic properties: transparency, translucency, or opacity. Transparent materials will pass or transmit all or most of the light incident on them. Translucent materials will also transmit most incident light, but will scatter it as it is transmitted. Opaque materials on the other hand will transmit no light, but will reflect or absorb the light. When light strikes a material that has any one of the above properties it can be reflected, transmitted, refracted, absorbed, or polarized.



## Candlepower Distribution

The most important set of data in artificial lighting design is the candlepower distribution. The candlepower distribution is the intensity of luminous energy from the luminaire in a particular direction.

### 1-4 Visual Comfort and Visibility

#### 1-4-1 Glare

To have a luminous environment that is visually comfortable, the occupants must not see any glare. Glare is defined as the result of excessive luminances in the field of view that are greater than the luminance to which the visual system is adapted. Physical discomfort (discomfort glare) or loss in visual performance and visibility (disability glare) can result from glare in the visual field.

There are many factors involved in producing glare. One is the length of time that the high luminance is present. Another factor is the luminance ratios between the glare sources and the surroundings in the major portion of the field of view. The task involved is another factor in glare. Important elements that cause glare are the light source, its size, luminance, position, and surrounding luminance. A very small bright source directly in the line of sight against a dark surrounding is an example of exaggerated glare.

Glare is complex and can be categorized into two major types - Direct and Indirect. Direct glare is due to excessively bright sources of light

(luminaires and/or windows) in the field of view which shine directly into the eyes; indirect glare is due to light sources that are reflected from tasks into the eyes.

Direct Glare (Visual Comfort) (Discomfort Glare)	Indirect Glare (Visibility) (Disability Glare)
Direct Glare	Reflected Glare Veiling Reflection

Direct and indirect glare Figure 1-4 (from CEL handbook)

The maximum luminaire luminance is a measured quantity. A photometer with a circular aperture of one square inch area is used to search the surface of the luminaire for the maximum luminance at the glare angles 45°, 55°, 65°, 75°, and 85°. The average luminance is calculated for each of the glare angles utilizing luminous intensity (candlepower) data. The ratio of the maximum to average luminaire luminance is computed.

To determine average luminance the equation Average Luminance (FL) =

$\frac{\text{candlepower @ } \theta \text{ (candela)}}{\text{projected Area @ } \theta \text{ (square inches)}} \times 144\pi$  is used. The candlepower is the luminous intensity at one of the glare angles,  $\theta$ ;  $144\pi$  is used to convert the average luminance ( $\text{cd/in}^2$ ) to footlamberts (fL). The projected area is the actual area of the luminaire times the cosine of the angle  $\theta$  measured from nadir. (The center of the plat is the center of the luminaire and nadir is

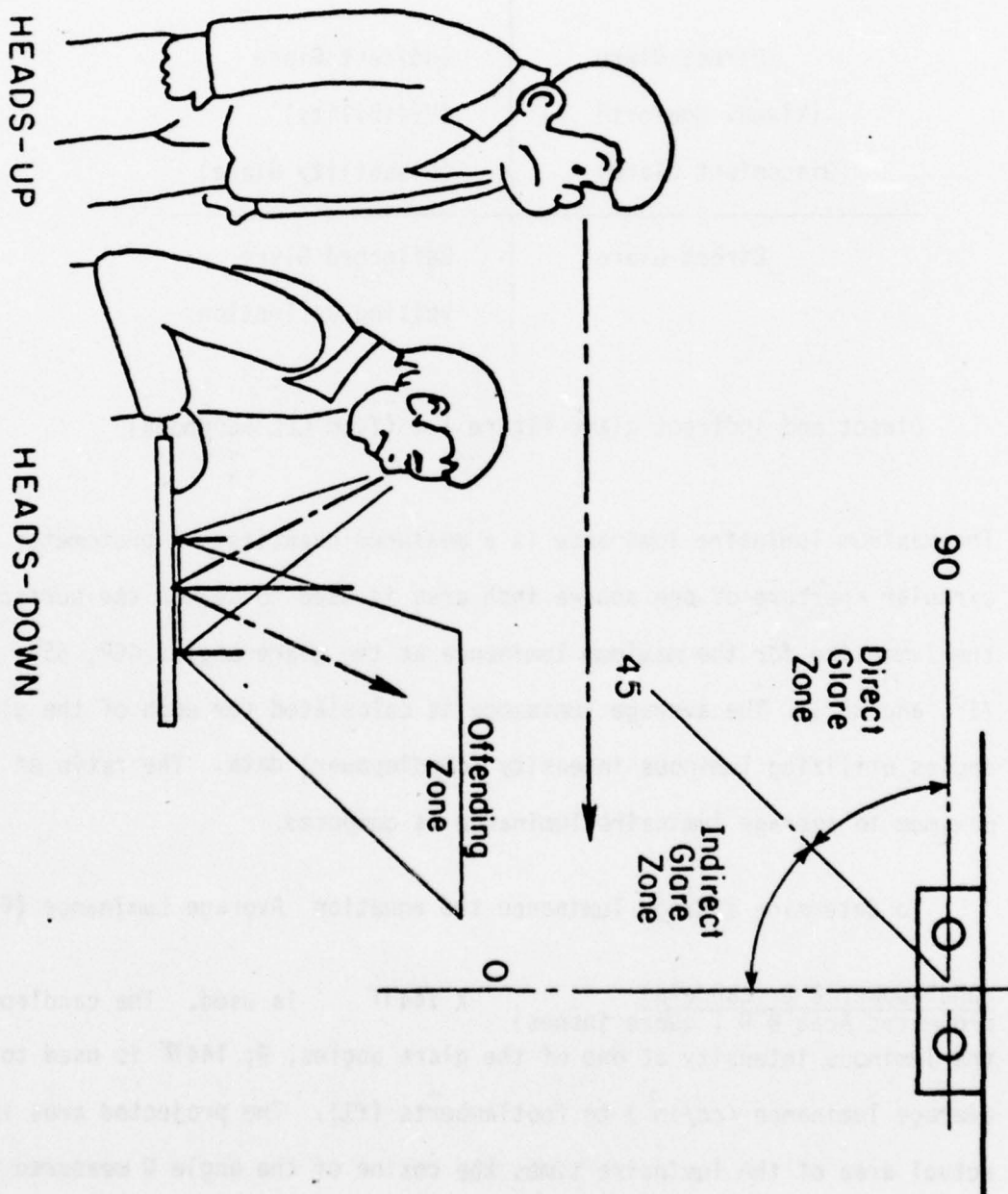


Figure 1-4 Direct and Indirect Glare

defined as straight down from that point).

The direct glare quality for a lighting installation can be determined by its VCP (visual comfort probability) rating. With a maximum rating of 100, the VCP rating of an office space should be 70 or better. It should be remembered that direct glare can be caused by daylighting as well as from artificial lighting.

The reflected glare is the result of specular reflections of high luminances from polished or glossy surface in the field of view. It usually is associated with reflections from within a visual task or from areas that in close proximity to the region being viewed. Even though "reflected glare" and "veiling reflection" are not synonymous, their quality can be evaluated by the same yardstick.

Veiling reflection is the result of surface reflection on the task which partially or totally obscures the details to be seen by reducing its contrast as if a sheer or translucent veil is being placed over the task. A lighting installation with a high degree of veiling reflection requires a higher level of illumination (raw footcandles) than the corresponding installation with a lower degree of veiling reflection. The concept of Equivalent Spherical Illumination (ESI) is developed to express the effective illumination level on a visual task subject to veiling reflection. The ESI value is highly directional. It is extremely difficult to express the ESI value on the task or in a space without defining the specific angle from which the task is being viewed and the relative positions between the task and luminaires. At the present state of art, the only practical



method of calculating the true ESI values on the task is by the use of computer programs.

## 1-5 Artificial Illumination Design Techniques

There are many techniques in artificial illumination design. Basically, they are variations of a few techniques that fall into two classifications - Quantity and quality.

### 1-5-1 Quantity Determination Methods

For many years only the quantity of illumination was determined. Although the quality of the illumination is considered today to be more important than the quantity, there are instances when the determination of the quantity will suffice. The basic technique in calculating illumination is the point-by-point method.

Point-by-Point. The point-by-point method of determining the direct component of illumination is an application of the basic law of illumination, the inverse square law:

$$E_n = \frac{I}{D^2} \quad \theta \quad (1)$$

The law states that the illumination,  $E_n$ , at a point on a surface normal to the light ray is equal to the luminous intensity,  $I$ , of the source arriving at the point divided by the square of the distance,  $D$ , between the source and point of measurement. This is shown in Fig 1-5 (from CEL handbook)



$$E = 1/D^2 \quad E_1 = 1/1 = 1 \text{ FC} \quad E_2 = 1/2^2 = 0.25 \text{ FC}$$

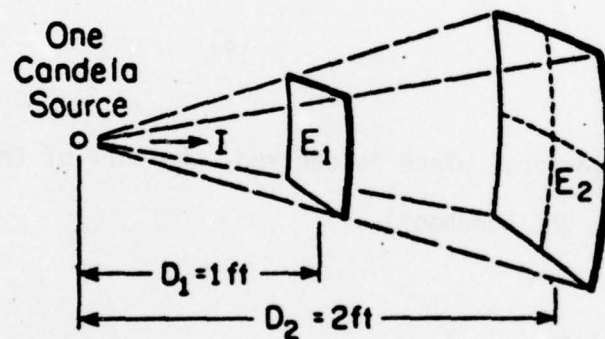


Figure 1-5: Inverse-Square Law of Illumination

The inverse-square law equation gives the illumination on a plane perpendicular to the direction of the incident light. When the plane of interest is at an angle to the incident light. Fig (1-6), the cosine law of illumination must be applied. The equation then becomes

$$E_h = E_n \cos \theta \quad (2)$$

Where  $E_h$  is the illumination on a horizontal plane due to flux incident at an angle  $\theta$  to the normal or replacing  $E_h$  in equation (2) with equation (1):

$$E_h = \frac{I \theta}{D^2} \cos \theta \quad (3)$$

If the illumination on a vertical plane is desired, the sine of the angle  $\theta$  is used. Fig (1-7). (From CEL handbook)

#### 1-5-2 Quantity and Quality

Common lighting practices have often confused quantity with quality. This has resulted in overlighted buildings, poor visual performance, increased cooling loads and excessive energy consumption. Criteria for lighting design should recognize the true needs of the user, both in lighting quality and in illumination quantity.

Footcandle (FC) is a unit measure of light. However, it indicates only the gross level of illumination without expressing its quality or actual usefulness. A room that has a high footcandle measurement may still be ineffective for the user to perform his or her visual tasks because of direct glare, reflected glare and/or veiling reflections.

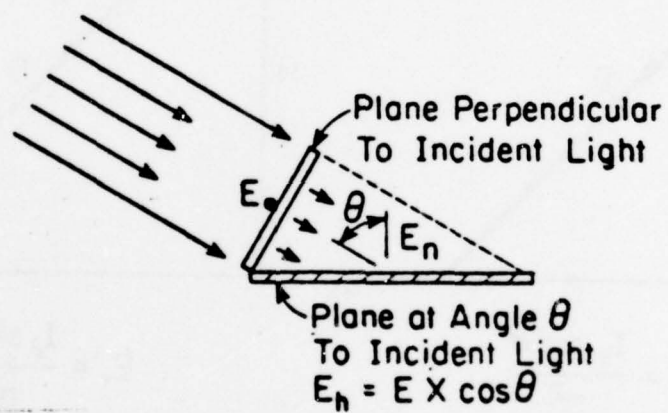


Figure 1-6 Cosine Law of Illumination

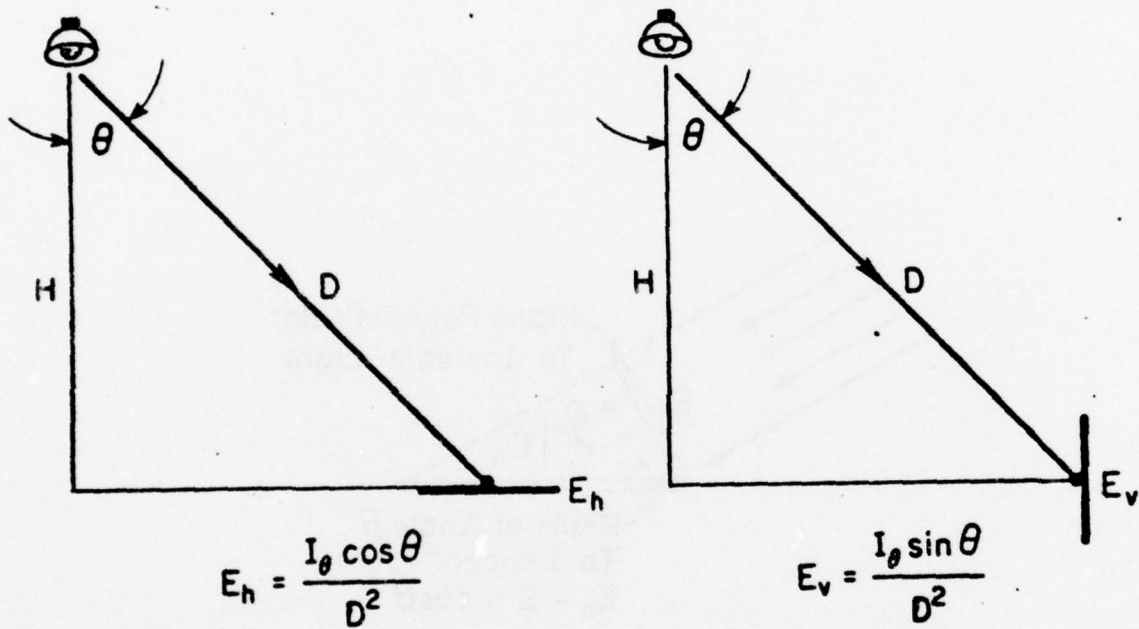


Figure 1- 7 Illumination on a Vertical and Horizontal Plane

## 1-6 The Luminous Environment

Artificial lighting is an interaction of luminous energy, the room, and the visual task to permit an individual to perform a visual task in a given environment.

The room is as important in artificial lighting as the task and luminaire.

There are seven characteristics of a room that have an impact on the the lighting. They are:

- 1 - Surface reflectances
- 2 - Size
- 3 - Shape
- 4 - Windows
- 5 - Maintenance
- 6 - Temperature and
- 7 - Furniture or equipment in the room

## II Controls

The numerous methods to control the lighting energy consumption fall into two basic categories. The first type of control provides for either an ON or OFF state; the second category provides ON-OFF control, but in addition provides the ability to select a level of energy consumption between on and fully off. This section discusses ON-OFF controls, level controls, and the state-of-the-art of a combination of the two.



## 2-1 ON-OFF Controls

The basic on-off control is the switch. Switches are available in a number of configurations, each suited to a particular function.

### 2-1-1 Circuit Breaker Switching

The National Electric Code requires all branch circuits to have circuit protection. Most branch circuit protection today is accomplished with circuit breakers. To save initial costs, many designs use that circuit breaker to switch the load. Although the initial cost of a switch leg is saved, circuit breakers *should not* be used in place of switches. The use of circuit breakers as switches is energy inefficient.

### 2-1-2 AC Snap Switches

The most common on-off device is the AC snap switch. The AC snap switch can be located almost anywhere within the room and can carry the full branch circuit load. For example, each private office should have at least one switch for the lights within that space and larger areas can be broken up into distinct work areas with a switch in each area. For a space with more than one entrance, three-way or four-way switches should be used to provide control at each entrance.

### 2-1-3 Time Switches

Above the assumption was made that a person would turn off the lights in his space whenever he left the room. This is not always true, so it has been suggested that systems be used to take over turning off the lights.

One such device is the time switch, most often used with sunlamps installed in bathrooms. One manufacturer provides models with timed cycles of 0-5 min, 0-15 min, 0-30 min, 0-60 min, 0-6 hr, and 0-12 hr. They also have 0-3 min, 0-60 min, and 0-12 hr times that feature a "hold" position for leaving the circuit closed continuously. The price is reasonable at about \$10 each.

With a time switch, the occupant of a space must actively turn on the lights but has to take no action to turn them off. Since the behavior of individuals related to the control of lighting is not really known, the economics of the time switch should be compared to both the single switch control of four offices and individual control in each office.

#### 2-1-4 Low Voltage Switching

Low voltage remote switching is not new on the market, but is gaining in importance. All low voltage systems consist of a magnetic relay, a transformer (putting out 24 volts or less), and switches which are interconnected with low voltage wiring. The relay switches the line voltage and current with a low voltage command from a low voltage switch in the space. This provides the ability to control loads from great distances, control a number of different loads from one location, and control one load from multiple locations.

Switches for a space can be placed in many locations such as the supervisor's office or guard station. Flexibility can be achieved easily with low voltage control. Each luminaire or any group of luminaires up to

branch circuit capacity can be grouped on a relay. The switching pattern then can be put together by connecting the low voltage wiring and switches as needed.

#### 2-1-5 Time Clocks and Photocells

The controls discussed in the previous sections require some human action to initiate a change of state. Time clocks and photocells are discussed together because they are conventionally used to control outdoor lighting such as security, parking lot, roadway, and area.

The most elementary time clock has a single ON time and single OFF time each day of the week. It has no provision to adjust for the seasonal changes in sunrise and sunset and thus must be continually adjusted when used in outdoor applications. Photocells can be used alone or in conjunction with other devices. To provide lighting at sunset that is not needed all night, a photocell can be used to turn on the lights, while a time control would turn them off at a preset time. When interfaced with low voltage remote switching, photocells provide another means of controlling the lighting system and its energy consumption.

#### 2-2 Level Control

##### 2-2-1 Dimmers

The best means of controlling the level of illumination is the dimmer. The original dimmers were resistance type that diverted some of the current through a variable resistor. Although the resistance dimmers have their

advantages and disadvantages, the only characteristic of importance here is that they do not save energy. The total power used is the same whatever the light level, because the dimmer itself draws power. Most existing dimmers of this type are used in theatrical and residential applications.

#### 2-2-2 Multilevel Ballasts

A second method of level control introduced in the past few years has been the multilevel ballast. The purchase of a small number of different items results in an increase in the initial cost of a building. With multilevel ballasts, only one type of luminaire and ballast need be specified for the job. Adjustments in level of illumination can be made by a simple wiring change. When retrofitting of existing installations is necessary, multilevel ballasts can save money and energy in overlit areas without greatly sacrificing uniformity.

#### 2-3 State-of-the-Art

A paper presented at the 1976 IES Annual Convention\* describes a computer controlled lighting control system. It combines remote on-off control with two-level illumination selection. The system consists of a controller and receiver/switch. The controller is a microcomputer and oscillator. The receiver/switch is a decoder and two relay switches. The microcomputer is programmed for different lighting patterns and the addresses of the luminaire.

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\*McGowan, T. K. and Feiker, G. E., "A New Approach to Lighting System Control" Journal of the Illuminating Engineering Society, October 1976



The address and condition codes generated are modulated by the oscillator and superimposed on the building electrical system line frequency. The message travels through the building electric distribution system. At the receiver/switch, a decoder takes the "message" off the line and if the address code corresponds to the one given that switch, the condition codes are executed, turning the luminaire fully on, halfway on, or off. A clock in the computer times the events allowing for different lighting patterns to be executed at different times of the day.

The advantages of a system of this type are many-fold. Because the commands are sent from the controller to the receiver/switch through the power lines, no rewiring is needed when retrofitting, no switch legs are needed, and no control wires in addition to regular wiring would be needed. If the cost of the receiver/switch is low, each luminaire in a building could be equipped with one. Since each would have its own address, any lighting configuration could be programmed. As the system exists now only preprogrammed configurations can be executed. With the microcomputer, various inputs can be used, such as time clocks, photocells, and/or remote input devices.

If the building has other functional HVAC, security, etc.) managed by a micro-processor/computer it can be used for fit lighting controls rather than a separate unit. The micro-processor/computer can then be hooked up in a master-slave configuration with a central micro or mini computer controlling the entire installation. This allows the system operator to adjust instruction to the microprocessor due to changes in build use or scheduling from the central control center. Being tied to a central system allows the Post



Engineer to coordinate lighting strategy post-wide with other conservation schemes.

The continuing development of microprocessor controlled lighting will bring about the desired flexibility while cutting costs and saving energy.

### III Combined Artificial/Daylighting Control Systems

This section analyzes the need of combined artificial/daylighting control systems. It briefly describes three systems investigated by the Naval Facilities Engineering Command and makes suggestions for modifications to the control systems.

#### 3-1 Investigation of Three Control Systems

The Naval Facilities Engineering Command conducted an investigation of available automatic lighting control systems. The investigation included an industry survey of commercially available control systems. The report<sup>\*</sup> evaluates one commercial and two CEL (Civil Engineering Laboratory) developed control systems. The investigation concludes that automatic control systems do conserve electrical energy.

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<sup>\*</sup> Smith, M. N., "Automatic Light Sensing and Control of Lighting Systems for Energy Conservation", Civil Engineering Laboratory, Naval Construction Battalion Center, Port Hueneme, California 1976

### 3-1-1 General Electric Light Sensing and Control System

The GE (General Electric) system consist "of a photo relay, a remote-control interface, low-voltage transformer, rectifier, relays, local switch, and override switches<sup>(1)</sup>." The system uses relays to turn luminaires off when a predetermined level of outside light is achieved. The photocell-sensor is positioned outside to read the lighting level.

The payback periods for five different geographical areas ranged from 2-8 to 3-8 years and for other areas from 3-5 to 5 years.

### 3-1-2 CEL Two-Level Automatic Light Sensing Control

The CEL (Civil Engineering Laboratory) two-level control system consists "of a photocell sensor, threshold level control, initial instant on, override switch, automatic on-off delay switch, gate driving circuit, and solid state switch<sup>(1)</sup>. The system uses a time delay circuit to provide power to a solid state switch which turns the lights on when the lighting level in an area drops below a preselected control setting (threshold). When the lighting level exceeds the threshold level, the delay circuit de-energizes the solid state switch to turn off the lights. The on-off delay circuit prevents cycling of the lights when an object, person, or cloud causes a momentary reduction in lighting level to the photocell sensor. The report<sup>(1)</sup> shows a payback period for five different geographical areas that ranged from 4.2 to 6.1 years for the single office tested.

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(1) CEL Automatic light sensing and control of lighting systems for energy conservation.

### 3-1-3 CEL Constant Illumination Level lighting Control System

The CEL constant level system consists "of a photocell sensor, input amplifier, level setting comparator, multi-indicator, electro-mechanical driver, and dimmer (1). The system makes use of fluorescent dimmers to maintain a constant level of illumination within the space. Therefore, each fluorescent luminaire must contain a dimming ballast. At this time, the system would be quite expensive for retrofit jobs where dimming ballasts are not present in the luminaires.

The test installation used a single photocell sensor located in the center of the room facing down towards the work surface. This system was superior to the two previous systems because of the more subtle changes in illumination in response to the daylight contributions. The payback period is longer for the CEL-constant level system, but the more desirable effect of maintaining a constant level of illumination may be worth the longer payback period. The uniform lighting conditions should result in an increase in productivity and performance because of the subtle changes in illumination level rather than the undesirable cycling and sudden variations experienced with the other systems.

#### IV Energy Consideration

##### 4-1 General

Currently, 80% of the resources used in this country are fossil fuels (coal, oil and natural gas)<sup>(2)</sup>. The most critical fuels in terms of estimated reserves are oil and natural gas. Of the total resources consumed, approximately 25% are used to generate electricity. Twenty percent of that 25% ends up as lighting. That means that approximately 5% of the total energy resources consumed in this country end up in the form of lighting. Approximately 9% of the 25% used to generate electricity involves oil and natural gas. That is, only 3% of the total energy resources used to generate electricity involves critical fuels. Within these facts, the question must be asked - Why is lighting a target for energy conservation? Lighting is "visible". Secondly, in term of the final end user, the lighting represents 30 to 50% of the operating cost of a building. Lighting energy conservation is important in terms of the total resource reserves and in term of operating cost for the building owner. As utility rates continue to increase, the impact of lighting on operating cost will become painfully apparent. Qualified lighting engineers have known for years that high levels of uniform lighting throughout a space are wasteful. For example, the IES lighting handbook recommends 100 footcandles at the task for general office work involving "hard pencil or poor paper reading fair reproductions".

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(2) Helms, R. N., Lighting and Energy Conservation - What is Reasonable?  
Electrical Consultant May 1975



#### 4-2 \* IES 12 Recommendations

In 1972, the IES prepared 12 recommendations (3), (4) for better utilization of energy in lighting design without sacrificing quality. The recommendations cover the operation, maintenance and selection of lighting equipment. The recommendations apply to new construction as well as renovations or retrofit (upgrade).

1 - Design lighting for expected activity (light for seeing task with less light in surrounding nonworking areas).

2 - Design with more effective luminaires and fenestration (use system analysis based on life cycle).

3 - Use efficient light sources (higher lumen per watt output).

4 - Use more efficient luminaires.

5 - Use thermal controlled luminaires.

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#### \* Illuminating Engineering Society

(3) Ringgold, P., "In the interest of illumination" lighting design and Application, November 1972, pp 1a - 6a

(4) Kaufman, J., "Optimizing the uses of energy for lighting", lighting design and application, October 1973



- 6 - Use lighter finish on ceilings, walls, floor and furnishings.
- 7 - Use efficient incandescent lamps.
- 8 - Turn off lights when not needed.
- 9 - Control window brightness.
- 10 - Utilize daylighting as practicable.
- 11 - Keep lighting equipment clean and in good working condition.
- 12 - Post instructions covering operation and maintenance.

#### 4-3 Conclusions

1. Expected Activity - A design approach that uses lower ambient levels with higher task levels will produce an energy efficient system. The task location must be known in order to supply the appropriate lighting level at the task location.

2. More effective luminaires and the fenestration system should be as efficient as possible without adversely affecting comfort (VCP) and visibility (ESI).

3. Efficient light sources - Selection should be based not only on the efficacy (lumens/watt) but also on the life, cost, and color rendition. Color should carry as much weight as the other factors since color has a direct bearing on the psychological behavior of the people which affects productivity and mood.

4. More efficient luminaires - Efficiency includes the utilization of energy in the space as well as cleaning and relamping convenience.

5. Thermal Control - Make use of the heat produced by the lighting equipment.

6. Reflecting surfaces - The absorption of light in a space due to low reflectance values will reduce the efficiency of the lighting system resulting in an increase in wattage.

7. Efficient incandescent lamps - If incandescent lamps must be used, the higher wattage lamps will be slightly more efficient than lower wattage lamps.

8. Lights off when not needed - Switching off lights when not in use will result in energy savings and a reduction in operating costs. The effectiveness of the energy reduction is a function of the flexibility of the control systems.

9. Window brightness - Excessive glare of windows on the line of sight will effect comfort and visibility which may reduce performance.

10. Daylighting - The effectiveness of daylight is dependent on the combined daylight/artificial lighting system. Unless the control system is properly designed, energy reduction is questionable.

11. Maintenance - Good maintenance will require fewer luminaires by increasing the utilization of the light entering space. Maintenance should include not only spot relamping but also room surface cleaning, painting, luminaire cleaning, and group relamping.

12. Operating and maintenance instructions - The design of sophisticated lighting systems and controls for energy conservation will be wasteful if the building user does not know how to properly use and maintain the system. The designer should provide instructions on how to use the system.

## V. REFERENCES

1 - IES Lighting Handbook

5th Edition, J. E. Kaufman and J. F. Christensen,  
Editors, New York

Illuminating Engineering Society of North America, 1972

2 - CEL Lighting Design Handbook

Ronald N. Helms and John M. McGovern  
Lum-I-Neering Associates

Civil Engineering Laboratory  
Naval Construction Battalion Center  
Port Hueneme, California 93043

3 - Smith, M. N. "Automatic Light Sensing and Control of Lighting  
Systems for Energy Conservation", 1976

Civil Engineering Laboratory  
Naval Construction Battalion Center  
Port Hueneme, California 93043

4 - Helms, R. N., Lighting and Energy Conservation - What is  
Reasonable? Electrical Consultant May 1975

5 - Ringgold, P., "In The Interest of Illumination" lighting design  
Application, November 1972,

6 - Kaufman, J., "Optimizing the uses of Energy for Lighting"  
Lighting Design and Application, October 1973



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